USING HEDONIC INDEXES TO MEASURE HOUSING QUANTITY

C. LANCE BARNETT

R-2450-HUD

OCTOBER 1979

HOUSING ASSISTANCE SUPPLY EXPERIMENT

Sponsored by

The Office of Policy Development and Research
U.S. Department of Housing and Urban Development

The research reported here was performed pursuant to Contract No. H-1789 with the Office of Policy Development and Research, U.S. Department of Housing and Urban Development. Statements and conclusions in this report are those of Rand's research staff and do not necessarily reflect the views of the sponsoring agency.

Library of Congress Cataloging in Publication Data

Barnett, C Lance, 1946-
Using hedonic indexes to measure housing quantity.

([Report] - Rand Corporation ; R-2450-HUD)
Bibliography: p.
1. Rental housing--Wisconsin--Brown Co.--Statistical methods. I. Title. II. Series: Rand Corporation. Rand report ; R-2450-HUD.
AS36.R3 R-2450 [HD7303.W6] 081s [301.5'4] 79-23282
ISBN 0-8330-0170-1

e Report is the principal publication doc-
major research findings and final research
other outputs of sponsored research for
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Published by The Rand Corporation

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PREFACE

This report was prepared for a conference on housing choices of low-income families sponsored by the Office of Policy Development and Research, U.S. Department of Housing and Urban Development (HUD). The conference was held in Washington, D.C., on 8-9 March 1979. The data presented here draw on research conducted by Rand as part of the Housing Assistance Supply Experiment (HASE).

The author wishes to thank the many individuals on the HASE staff who contributed directly or indirectly to the collection and processing of the data used in this analysis. Special acknowledgments are due to Daniel A. Relles, who provided consistently sound advice on statistical issues; to Ira S. Lowry, Kevin F. McCarthy, Charles W. Noland, and C. Peter Rydell, who reviewed an earlier draft and offered excellent suggestions for its improvement; to Dennis deTray and William McNaught, who reviewed the draft and provided detailed comments; to Judy Bartulski and Jan Newman, who typed the successive drafts; and to Judy Rasmussen, who edited the report.

The report was prepared under HUD Contract H-1789.

SUMMARY

A major problem faced by any researcher studying the characteristics of the rental housing market and the behavior of its participants is that although rent is directly observable, the services a dwelling supplies and the prices of those services are not. Hedonic indexing is one way to overcome that problem. A hedonic index for housing (or any other complex good) is most easily described as a regression equation that relates the attributes of dwellings and locations to gross rent, the sum of tenants' payment to landlords and for utilities. If the market for housing is perfectly competitive and in equilibrium, the regression coefficients can be interpreted as market prices that clear the market for each attribute individually and all attributes jointly. Weighting the attributes of dwellings by those prices, disparate attributes such as the number of rooms, type of heating system, and quality of the neighborhood can be summed to yield measures of services supplied by dwellings that are comparable across dwellings and over time.

This report presents a hedonic index fit to data that describe Brown County, Wisconsin's rental housing stock in 1974. The data were collected as part of the Housing Assistance Supply Experiment (HASE), funded by the U.S. Department of Housing and Urban Development (HUD). HASE's purpose is to help HUD judge the desirability of using housing allowance programs to enable low-income families to afford safe, decent, and sanitary housing without spending more than a quarter of their income. The data come from surveys that address the owners, occupants, buildings, and neighborhoods of a marketwide probability sample of residential rental properties. The data are an exceptionally rich source of information with which to fit a hedonic index: For each of 1,736 dwellings, more than 200 attributes were compiled from over 400 survey items.

The index presented here consists of 17 attributes that describe the interiors and exteriors of dwellings and 6 that describe the location of the dwellings. In addition, the regression equation used to fit the index includes four variables that adjust gross rents for price

discounts some tenants received. If the relative importance of variables is measured by how much those variables contribute to the accuracy with which the regression predicts gross rent, location attributes and price adjustments are least important. Excluding them reduces the index's accuracy by only about 9 percent. The most important attributes are those measuring the interior quality of dwellings, followed by those measuring the spaciousness of dwellings and those describing exterior quality.

The regression fits the data well. It predicts the gross rent of individual dwellings with a standard error of $20 or 15 percent of average monthly gross rent ($137). With only one exception, the estimated attribute prices and price adjustments have signs that agreed with logical expectations. When external evidence on attribute prices is available, it confirms that their estimated magnitudes are roughly correct.

Most of the housing attributes in the index refer to structural features that are unlikely to change over the life of the dwelling except by substantial remodeling or rehabilitation. Since the allowance program rarely engenders such actions, the index will probably not be sensitive to allowance-induced changes. On the other hand, the index will be valuable for studying housing markets, household choices, and landlord behavior.

To demonstrate that the index will be a useful analytical tool for HASE, the report first confirms that the estimated prices satisfy the conditions necessary for dwellings to be treated as if they provide homogeneous and comparable flows of services (i.e., that the attributes of dwellings are a composite commodity). It then presents two ways the index can be used to study households' housing choices. The first is to determine whether alternative search strategies enable households to find bargains (dwellings renting at significant discounts compared with their hedonic rents).* The evidence indicates that the most effective way to find bargains is through tips from friends.

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*Alternative search strategies for finding bargains are only outlined here. See Kevin F. McCarthy, *Housing Search and Residential Mobility*, The Rand Corporation, R-2451-HUD, September 1979, for a complete presentation of the analysis and its implications.

The second use is to show the effects of renters' income on their consumption of four summary attributes: space, interior quality, exterior quality, and location. The findings are plausible. The consumption of space varies less with income than does the consumption of interior and exterior quality. Higher income renters tend to buy "better" rather than "more" housing. Although the consumption of location does not vary with income, its composition does. Higher income renters live farther from the center of town, preferring better neighborhoods to access.

Overall, the evidence presented here indicates that the index for Brown County will be a valuable tool for studying the characteristics of its housing market and the behavior of participants in that market.

CONTENTS

TABLES

I. INTRODUCTION

This report presents and appraises the usefulness of a hedonic index for measuring services of rental dwellings in Brown County, Wisconsin.* Its appraisal shows that the index will be a valuable tool in analyzing that housing market. An excellent data base allowed me to test numerous specifications and thus obtain a good statistical fit and plausible estimated prices. Because of Brown County's market characteristics, the index can measure differences in the services supplied by dwellings in different markets or from the same dwellings at different times. Even though the index will probably not distinguish small changes caused by the allowance program from zero, it is capable of distinguishing differences in the prices paid for dwellings as well as the composition of services supplied by them. The work presented here will be extended to include fitting a similar index with data for rental housing in St. Joseph County, Indiana, and with data for owner-occupied dwellings in both counties.

The remainder of this section briefly reviews the theory of hedonic indexing and its implications for the choice of variables and functional form. It then describes the Brown County data base and presents evidence that shows it meets the requirements for estimating valid attribute prices. Finally, it previews the characteristics of the fitted index.

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*Brown County is one of two housing markets (the other is St. Joseph County, Indiana) being studied by the Housing Assistance Supply Experiment (HASE) to help the U.S. Department of Housing and Urban Development assess the desirability and feasibility of using housing allowances to enable low-income families to afford safe, decent, and sanitary dwellings. HASE was explicitly undertaken to measure the price effects of a fullscale housing allowance program. The work presented here was initially begun in the hope that the index could be used to measure those price effects. See C. Lance Barnett, *Using Hedonic Indexes to Measure Supply Response to Housing Allowances*, The Rand Corporation, WN-8686-HUD, August 1976 (forthcoming as N-1069-HUD).

THEORY OF HEDONIC INDEXING

To compare the services of dwellings in different markets or services of the same dwelling at different times, one needs a cardinal unit of account that is invariant under different market conditions. Hedonic index numbers, if properly estimated, provide such a unit of account. They are weighted sums of directly observable attributes of dwellings and locations that are not themselves directly commensurable but that jointly account for the services dwellings provide. The weights are chosen so that within at least one housing market, index numbers for different dwellings approximate market rents.

Many attempts have been made to specify the attributes that should compose a hedonic index for housing service and to estimate their coefficients.* Specifying attributes has usually been narrowly constrained by the descriptive data available for an adequate sample of dwellings. Estimating coefficients has consistently been done by regressing a measure of each dwelling's market value on the values of its attributes, testing alternative specifications for goodness of fit. The regression coefficients are then interpreted as prices for the attributes to which they pertain. The validity of that interpretation rests on a theory of market transactions in multidimensional commodities.

Here, to index housing and location services, it is assumed that consumers value the attributes of dwellings (such as number of rooms, ceiling height, plumbing facilities, and neighborhood quality) rather than dwellings per se. It is also assumed that consumers have weakly separable utility functions,** with one branch of those functions containing all and only the attributes of dwellings. Consequently, their

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*See, for example, Robert F. Gillingham, *Place-to-Place Rent Comparisons Using Hedonic Quality Adjustment Techniques*, U.S. Bureau of Labor Statistics, Staff Paper 8, 1975.

**For a discussion of separable utility functions and their implications for demand analysis, see Robert H. Strotz, "The Empirical Implications of a Utility Tree," *Econometrica*, Vol. 25, 1957, pp. 269-280; William M. Gorman, "Separable Utility and Aggregation," *Econometrica*, Vol. 27, 1959, pp. 469-481; and Steven M. Goldman and Hirofumi H. Uzawa, "A Note on Separability in Demand Analysis," *Econometrica*, Vol. 32, 1964, pp. 387-398.

choice of attributes depends only on attribute prices and how much they want to spend on housing.

Although landlords offer such housing attributes in bundles, they can and do alter what the bundles include. Ordinary market transactions can therefore produce a consensus on the attribute prices. If a housing market has many participants, competition among the buyers and sellers will clear the market for each attribute individually and all attributes jointly. If a perfectly competitive housing market is in equilibrium, attribute prices are the solution to the simultaneous equation system composed of many individual demand and production functions. Attribute prices are marginal prices facing both consumers and suppliers and thus represent the market's consensus about marginal rates of substitution among the attributes.

Current theory is not powerful enough to indicate what functional form the index should have.* There is widespread agreement, however, that if the attributes composing the index are measured in natural units (e.g., number of rooms), the index is likely to be nonlinear. If so, marginal prices will not equal average prices--a troublesome result because regressions yield estimated coefficients that are best interpreted as averages. In this study, attributes are transformed as needed, so that their marginal and average prices will be equal. The functional form consistent with such prices is linear:

$$R_i = x_i\beta + z_i\gamma, \tag{1}$$

where R_i = rent for dwelling i,

x_i = $1 \times k$ vector of housing attributes for dwelling i,

β = $k \times 1$ vector of housing attribute prices,

z_i = $1 \times g$ vector of location attributes for dwelling i,

γ = $g \times 1$ vector of location attribute prices.

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*See, for example, Sherwin Rosen, "Hedonic Prices and Implicit Markets," *Journal of Political Economy*, Vol. 82, 1974, pp. 34-55.

Equation (1) defines a hedonic index for residential services, which are composed of housing and location services. The term $x_i\beta$ measures housing service; $z_i\gamma$ measures location service. The two services are distinguished here to measure changes in the quantity of housing service. Because attribute prices will not vary in the market when it is in equilibrium, differences in expenditure must be due to differences in the quantity of attributes consumed. Arbitrarily defining the unit of quantity so that the price of a unit of housing or location service equals one causes the total quantity to equal expenditure.

Intertemporal changes in the quantity of housing service for a given dwelling equal the changes in the dwelling's housing attributes weighted by the attributes' prices:

$$\Delta q_h = (x_t - x_s)\beta_s, \tag{2}$$

where Δq_h = the change in the quantity of housing service between times t and s ($s < t$),

x_t , x_s = $1 \times k$ vectors of attributes for a given dwelling at times t and s,

β_s = $k \times 1$ vector of attribute prices for time s.*

Equation (2) can also be used to measure cross-sectional differences in the quantities of housing services by substituting x_i and x_j for x_t and x_s, where x_i and x_j are the vectors of attributes for dwellings i and j. Moreover, equations that are similar to Eq. (2) can be used to measure cross-sectional or intertemporal differences in the quantity of location services supplied or consumed. Such equations, then, can be combined to measure differences in residential services.

The index is a linear function of the attributes,** which affects the interpretation of an attribute's price. First, its price does not

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*Any price vector can be used to measure intertemporal changes. Equation (2) uses base period prices, so it is a Laspeyers quantity index. If it used end period prices, it would be a Paasche quantity index. The use of either period can lead to well-known ambiguities; see Barnett, *Using Hedonic Indexes to Measure Supply Response*.

**Hedonic indexes are frequently specified with log-linear form; see, for example, Sally Merrill, *Draft Report on Hedonic Indices as a Measure of Housing Quality*, Abt Associates, Cambridge, Mass., Report 76-96R, 23 December 1977.

vary with the quantity of the attribute consumed. For example, if a bathroom is added to a dwelling and if bathrooms are worth $18 per month, then adding one bathroom increases the quantity of housing service by 18, regardless of the original number of bathrooms. Second, the price of an attribute does not vary with the quantity of other attributes. The increase in quantity of housing service provided by an extra bathroom does not depend on the location of the dwelling or on other attributes such as the number of other rooms in the dwelling.

Equation (1) readily converts to a regression equation,

$$R_i = x_i\beta + z_i\gamma + \varepsilon_i, \tag{3}$$

where ε_i = a random error term. At this level of generality, the error term represents random variation in the price of residential services.* Such variation in rents for similar dwellings should be present because the buyers and sellers of housing are unlikely to have complete knowledge of the housing market. As long as it is truly random and reasonably small, such variation does not adversely affect the estimated prices.

BROWN COUNTY DATA BASE

The data needed for hedonic indexing were assembled by combining parts of the baseline household, residential building, and neighborhood and landlord surveys.** The household survey provided counts

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*In the actual regression, the error term also contains excluded attributes.

**Those surveys, fielded mostly in 1974 (before the allowance program began), provide a benchmark for assessing the program's effect. The landlord survey was addressed to the owners of a marketwide probability sample of residential rental properties. The household survey solicited information from the occupants of dwellings on those properties. The residential building survey used trained fieldworkers who examined each building on those properties and reported on its characteristics. The neighborhood survey collected facts from local public sources about the 108 neighborhoods into which Brown County had been divided. It also used trained fieldworkers who observed each blockface in the county and reported on its characteristics.

of rooms and bathrooms, ratings of interior quality, indicators of whether attributes such as steam heat or thermostats are present in the dwelling, and tenant characteristics such as length of stay and satisfaction with a dwelling. The residential building survey furnished ratings of exterior quality, indicated type of exterior construction material (e.g., composition siding), and described the blockface where the dwelling is located. The neighborhood survey gave details of the neighborhood's quality, characteristics, and location. The landlord survey indicated whether the property had a resident landlord and also gave the landlord's assessment of building quality.

The data base was constructed in several steps. First, 2,573 rental dwellings on properties whose occupants, landlords, and buildings we survey annually were identified. That set of dwellings excluded mobile homes and dwellings occupied by roomers or lodgers because they presented special analytical problems. All dwellings that lacked a complete interview for either the household, residential building, or landlord survey were dropped from the data base, leaving 2,014 records.

The second step entailed linking data from the four surveys. Because the household survey has the same unit of observation (the dwelling) that is used to fit the index, each record in the data base contains data from only one household record. Two or more dwellings may occupy the same building, so data from one residential building report may be repeated in the records of several dwellings. Similarly, data from one landlord or neighborhood may be included in the records of several dwellings.

Next, about 200 analysis variables were compiled for each record and were used to trim the data base. Records were then excluded from the data base if they satisfied one or more of the following conditions: (a) data were incomplete, (b) tenant was related to the landlord, (c) tenant stated that he paid less than full market rent, or (d) dwelling was located on a property that was also used for farming. After those exclusions, 1,736 records remained in the data base.

In addition to the requirements just presented, the data must also have come from a market that is in equilibrium or from one that divides into a few submarkets that are in equilibrium. In the absence of

equilibrium, attribute prices might vary greatly among dwellings and could not be accurately estimated. On the other hand, attribute prices that fit poorly might indicate that the market divides into submarkets supporting different attribute prices. If so, Eq. (3) could be separately fit for each submarket,* assuming the individual submarkets were in equilibrium.

A study of rent inflation in Brown County provides the best available evidence that its rental housing market was in equilibrium at baseline.** That study computed the inflation rates of contract and gross rent (contract rent plus tenant-paid utilities), using longitudinal data that cover a period of 54 months beginning slightly before baseline.

If the rental market were much out of equilibrium, rates of change in gross rents would vary greatly among dwellings, since individual landlords would be adjusting both prices and quantities as they searched for the equilibrium values. That did not occur in Brown County. During the 54-month period mentioned earlier, the average annual rate of inflation was 6.64 percent with a standard error of .19. The annual rates for 1974, 1975, and 1976 have similarly small standard errors of about .37. When average annual rates are computed for dwellings grouped by number of rooms, the range of values is uncomfortably wide--from 5.82 percent for one- or two-room dwellings to 9.01 percent for six- or more room dwellings. However, the standard errors are reassuringly small, never exceeding .6. The wide range is probably due to the differential use of fuel for space heating combined with the rapid inflation of fuel prices following the 1973 oil embargo. Although that event could easily disrupt a market, it could not have influenced Brown County's rental market in early 1974 when the data used here were collected.

PREVIEW OF FINDINGS

A hedonic index was fitted to data drawn from surveys of rental properties in Brown County before the experimental allowance program

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*Section III investigates whether Brown County's housing market at baseline divides into submarkets.

**James P. Stucker, *Rent Inflation in Brown County, Wisconsin: 1973-78*, The Rand Corporation, WN-10073-HUD, August 1978 (forthcoming as N-1134-HUD).

began. In its final specification, the regression used to fit the index contains 27 variables, of which 17 are housing attributes, 6 are location attributes, and 4 are price adjustments (see Table 1). These variables are a subset of about 200 (derived from over 400 survey items) that were tested. The coefficient of each included variable is

Table 1

DETAILED COMPONENTS OF THE HEDONIC INDEX FOR RENTAL DWELLINGS: BROWN COUNTY, WISCONSIN, 1973

Summary Attributes	Detailed Components
	Housing Attributes
Space	Number of rooms (ln) Number of bathrooms

Interior quality	Composite rating of interior quality
	  Window rating
	  Wall and ceiling rating
	  Floor and floor covering rating
	  Building rating
	Number of appliances supplied by landlord
	Storage space[a]
	Central or steam heat[a]
	Thermostat[a]
	Subdivided residential space[a]

Exterior quality	Composite rating of exterior quality
	  Roof rating
	  Wall rating
	  Window rating
	  Storm window rating
	  Sidewalk and driveway rating
	  Exterior repair rating
	  Overall cleanliness rating
	  Overall condition rating
	  Construction quality rating
	  Building rating
	Composite rating of comparative building quality
	  Landlord's rating
	  Tenant's rating
	  Fieldworker's rating
	Lot size per dwelling (sq ft)
	Wood or composition siding[a]

Table 1 (continued)

Summary Attributes	Detailed Components
	Housing Attributes (continued)
Exterior quality (continued)	Garage or carport[a] Single-family[a] Duplex[a] 5-9 dwellings on property 10+ dwellings on property
	Location Attributes
Access to employment	Logarithm of neighborhood employment inversely weighted by airline distance
Neighborhood quality	Composite rating of neighborhood quality Building rating Yard rating Cleanliness rating Fraction of neighborhood that is open space
Blockface quality	Consumer shops[a] Institutions[a] Above average landscaping[a]
	Other
Price adjustments	Number of years since current tenant moved in: length of stay Tenant's satisfaction with dwelling Resident landlord[a]
Constant term	Correction for incorrect zero points on attribute scales
Error term	Missing attributes; random price variation

SOURCE: Compiled by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

[a]Variable indicates whether attribute is present.

significantly different from zero at the 67 percent confidence level, and most are significant at the 95 percent level.

The equation's standard error of estimate is $20, or about 15 percent of the mean monthly gross rent. In goodness of fit, it compares

well with other fitted indexes for housing. All its variables have coefficients whose signs and magnitudes can be reasonably explained and which in some cases are roughly confirmed by independent evidence.

Fourteen of the 17 housing attributes in the index are structural features that are unlikely to change over the life of a dwelling except by major remodeling or rehabilitation. Therefore, the index will be insensitive to the kinds of housing improvements likely to result from a housing allowance program. Such improvements would be reflected primarily in three composite quality ratings whose standard deviations in the baseline data are small (.34 to .51) and whose price coefficients are all under $6. On the other hand, if receiving allowances induced households to add rooms or install masonry siding, the index would reflect those improvements.

I do think the index will be useful for studying the factors that affect landlords' maintenance and repair expenditures. When residential prices differ across markets or submarkets (because of location or different supply-demand relationships), the index will enable us to distinguish housing service values from location values and thus normalize expenditures per unit of housing service.

The index will also be a valuable tool for studying the characteristics of Brown County's housing market and the behavior of its participants because it converts disparate measurements on individual attributes into comparable measures of services. Section III verifies that the index can be used in this way. It then shows two ways that the index can be used to better understand renters' housing choices: to determine whether some search strategies are better than others at locating bargains, and to describe renters' marginal propensities to consume space, interior quality, exterior quality, and location.

II. A HEDONIC INDEX FOR BROWN COUNTY

Attribute prices cannot be directly observed because transactions between landlords and tenants concern bundles of attributes. However, the composition of those bundles varies, allowing individuals to determine the approximate prices of attributes by comparing rents of dwellings that closely resemble one another. Such determinations can also be made by using regression analysis.

This section presents a hedonic index for rental dwellings in Brown County in 1974. It begins by explaining why monthly gross rent is the appropriate dependent variable for the regression used to fit the index.* It then shows the importance of the independent variables (attributes and price adjustments) for determining monthly gross rent. Next, it details the construction of those variables and, when possible, assesses the magnitudes and signs of their coefficients. The section closes by appraising the likelihood of serious specification error.

DEPENDENT VARIABLE

Gross rent per month (contract rent plus tenant-paid utilities) is the dependent variable used here. It is the appropriate variable because competition among tenants and landlords should equate the gross rents of dwellings offering comparable services. Consider, for example, two identical dwellings located in the same neighborhood. Competition would equate their gross rents. Consider also two identical dwellings located in different neighborhoods but the same market. Competition would again force their gross rents to differ by an amount proportional to the difference between the location services supplied. Similarly, for dwellings offering the same location services but different housing services, competition would force their rents to differ by an amount proportional to the difference in housing services supplied.

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*Because price adjustment variables are included among the independent variables, the regression equation is not identical to the hedonic index. I do, however, occasionally use the terms *regression* and *index* synonymously.

INDEPENDENT VARIABLES

Variables composing the hedonic index were chosen for theoretical and practical reasons. For theoretical reasons, variables determining the demand for or supply of attributes were excluded. The hedonic index represents the reduced-form solution to a simultaneous system of demand and supply equations, so that including variables such as tenant's income or price of land in the index ought to identify those underlying equations.

Individual attributes were rescaled so their average and marginal prices would be equal.* For example, if additional rooms have declining marginal values in the marketplace, which would cause marginal and average prices to diverge, rooms should be rescaled. Here the natural logarithm of the number of rooms is used, a transformation that incorporates declining marginal value.

For practical reasons, condition ratings for the specific features of a dwelling (windows, walls, floors, etc.) were replaced with averages of the ratings for logically grouped features. Using such composite ratings forestalls the collinearity problems that would result from including the specific ratings in the regression. Moreover, the composite rating ought to have smaller observation errors than many of the individual components; therefore, using this rating should reduce the effects of such errors.

Rents are affected by factors other than the quantity of service provided. Landlords, for example, tend to raise rents more when tenants move than they do for current tenants, so that current tenants often enjoy price discounts. Also, dwellings on properties with resident landlords tend to rent for less than otherwise comparable dwellings. The regression includes variables to adjust the rent for such price discounts.

Only variables whose coefficients' t-value exceeded one were included in the regression, because satisfying that condition minimizes the standard error of the estimate and hence the index's prediction error.**

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*All attributes except dummy variables for the presence or absence of an attribute are scaled so that larger values are better. Thus, a priori all such attributes should have positive prices.

**See Yoel Haitovsky, "A Note on the Maximization of $\bar{R}^2$," *The American Statistician*, Vol. 23, 1969, pp. 20-21.

Reducing both errors increases the accuracy with which the index can measure the quantity of housing and location services, cross-sectional differences in services provided by different dwellings, and the change in services provided by a dwelling over time.

Table 2 lists the attributes chosen to compose the index as well as the variables included in the regression to adjust for differences in the price of residential service; it also gives their means and standard deviations. The attributes are separated into two major groups: those that measure the quantity of housing service and those that measure the quantity of location service. Each major group comprises three categories of attributes: for housing services, space, interior quality, and exterior quality; for location services, access to employment, neighborhood quality, and blockface quality. The housing categories differentiate housing "quantity" and "quality": Units that are similar in size may differ in other respects.

Table 3 shows the importance of the summary attributes in determining a dwelling's monthly gross rent. To judge the importance of the attributes, we used a five-step procedure that at each step deleted from the marketwide regression the one whose exclusion least increased the regression's standard error.* Location attributes were dropped first, since their exclusion only slightly increases the standard error from $20.00 per month to $20.53. Price adjustments were dropped next, which increased the standard error to $21.80 or by 9 percent relative to the marketwide regression's standard error. Of the remaining summary attributes, exterior quality is third most important, space second, and interior quality the most important. This pattern appears again in Sec. IV, where the index is used to show the change in the amount renters will spend on summary attributes as their income rises.

The next part of this section explains how independent variables were constructed and discusses their coefficients, which are presented in Table 4.**

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*Dropping a summary attribute means dropping all the attributes composing it.

**The coefficients in Table 4 were estimated with a generalized least squares procedure that accounts for differences in error term variance among dwelling types.

Table 2

MEANS AND STANDARD DEVIATIONS FOR VARIABLES USED TO FIT A HEDONIC INDEX FOR RENTAL DWELLINGS: BROWN COUNTY, WISCONSIN, 1973

Variable	Range of Values	Statistics	
		Mean	Standard Deviation
Dependent Variable			
Gross rent ($/month)	40–323	137.42	33.03
Housing Attributes			
Space			
Number of rooms (ln)	0–2.4	1.31	.30
Number of bathrooms	1–5	1.02	.13
Interior Quality			
Composite rating of interior quality	0–3	2.61	.51
Number of appliances supplied by the landlord	0–25	5.61	6.00
Storage space	Yes = 1, no = 0	.91	.29
Central or steam heat	Yes = 1, no = 0	.87	.34
Thermostat	Yes = 1, no = 0	.85	.36
Subdivided residential space	Yes = 1, no = 0	.16	.37
Exterior Quality			
Composite rating of exterior quality	0–3	2.41	.34
Composite rating of comparative building quality	0–2	1.31	.34
Lot size per dwelling (000 sq ft)	1–10.9	3.50	2.68
Wood or composition siding	Yes = 1, no = 0	.37	.48
Garage or carport	Yes = 1, no = 0	.52	.50
Single-family dwelling[a]	Yes = 1, no = 0	.11	.31
Duplex[a]	Yes = 1, no = 0	.08	.27
5–9 dwellings on property[a]	Yes = 1, no = 0	.42	.49
10+ dwellings on property[a]	Yes = 1, no = 0	.11	.32
Location Attributes			
Access to Employment			
Generalized access to employment	0–25.4	1.91	.53
Neighborhood Quality			
Composite rating of neighborhood quality	0–3	1.89	.38
Fraction of neighborhood that is open space	0–.86	.34	.25

Table 2 (continued)

Variable	Range of Values	Statistics	
		Mean	Standard Deviation
Location Attributes (continued)			
Blockface Quality			
Consumer shops	Yes = 1, no = 0	.34	.47
Institutions	Yes = 1, no = 0	.11	.31
Above average landscaping	Yes = 1, no = 0	.94	.23
Price Adjustments			
Length of stay (yrs)	0-18.5	2.94	4.81
Length of stay exceeding 3.5 years	0-15.0	1.05	4.16
Tenant's satisfaction with dwelling	0-3	2.39	.75
Resident landlord	Yes = 1, no = 0	.11	.32

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

NOTE: Analysis used only data for those dwellings whose occupants stated they paid full market rent and only when complete information on variables listed was available.

[a]Excluded category is nonduplex dwellings on 2-4 dwelling properties.

Space

Two attributes measure the amount of space provided by a dwelling: the logarithm of the number of rooms (excluding bathrooms) and the number of bathrooms. Efficiency dwellings with complete kitchen facilities are assumed to have 1.5 rooms. The number of rooms is rescaled by using the natural logarithm to reflect that additional rooms have declining marginal value.* The estimated price for rooms is highly significant; t = 23.9, the largest t-value in the regression. Half-baths** are

*At the end of this section, residuals are analyzed to verify that presumption.

**A half-bath has either a flush toilet, a bathtub, or a shower, but does not have all the facilities of a complete bathroom.

Table 3

CUMULATIVE EFFECTS OF EXCLUDING SUMMARY ATTRIBUTES ON THE INDEX'S STANDARD ERROR

Excluded Summary Attributes	Standard Error	
	$/Month	Increase (%)
None	20.00	0.0
Location	20.53	2.7
Location, price adjustments	21.80	9.0
Location, price adjustments, exterior quality	24.39	22.0
Location, price adjustments, exterior quality, space	28.19	41.0
All[a]	33.03	65.2

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

NOTE: Summary attributes were excluded in the order that least increased the standard error at each step.

[a]All consists of location, price adjustments, exterior quality, space, and interior quality, which exhausts the variables that compose the regression used to fit the marketwide index.

given a value of .5. (Earlier regressions consistently yielded estimated prices equal to one-half the price of full bathrooms.)

Interior Quality

Six attributes measure the interior quality of dwellings. The composite rating of interior quality combines tenants' appraisals of a dwelling's interior into a direct measure of interior quality. The remaining five attributes use evidence on the presence or absence of various dwelling characteristics to indirectly measure interior quality.

The composite rating of interior quality is a simple average of condition ratings provided by tenants for their dwellings' windows, walls and ceilings, floors and floor coverings, and their building. As shown in Table 5, each rating uses a 4-point scale. The ratings indicate that most tenants occupy dwellings whose interiors are good.

Table 4

REGRESSION STATISTICS FOR A HEDONIC INDEX FOR RENTAL DWELLINGS: BROWN COUNTY, WISCONSIN, 1973

Variable	Statistics	
	Estimated Price ($/mo.)	*t*-value
Housing Attributes		
Space		
Number of rooms (ln)	46.70	23.89
Number of bathrooms	18.86	4.74
Interior Quality		
Composite rating of interior quality	5.07	3.73
Number of appliances supplied by the landlord (sq)	1.11	9.22
Storage space[a]	3.95	2.22
Central or steam heat[a]	13.82	8.85
Thermostat[a]	9.90	6.28
Subdivided residential space[a]	-4.84	-3.06
Exterior Quality		
Composite rating of exterior quality	5.60	2.92
Composite rating of comparative building quality	5.80	3.26
Lot size per dwelling (000 sq ft)	1.27	4.24
Wood or composition siding[a]	-6.08	-4.65
Garage or carport[a]	3.16	2.77
Single-family dwelling[a]	3.81	1.75
Duplex[a]	31.12	13.90
5-9 dwellings on property	4.91	2.96
10+ dwellings on property	8.78	3.91
Location Attributes		
Access to Employment		
Generalized access to employment	7.86	4.61
Neighborhood Quality		
Composite rating of neighborhood quality	9.39	5.94
Fraction of neighborhood that is open space	9.92	2.64
Blockface Quality		
Consumer shops[a]	-3.69	-3.35
Institutions[a]	-5.54	-3.46
Above average landscaping[a]	5.03	2.12

Table 4 (continued)

Variable	Statistics	
	Estimated Price ($/mo.)	t-value
Price Adjustments		
Length of stay (yrs)	-4.45	-9.81
Length of stay exceeding 3.5 years	3.86	7.45
Tenant's satisfaction with dwelling	-4.69	-5.84
Resident landlord[a]	-2.31	-1.39
Other		
Constant term	-35.58	-4.34

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

NOTE: Regression analysis uses only data for those dwellings whose occupants paid full market rent and only when complete information on variables listed was available. F = 111.98 with 27 and 1,708 degrees of freedom, R^2 = .64; standard error of the estimate = 20.00.

[a]Variable indicates whether attribute is present.

Building rating is included in the composite rating because it should incorporate tenants' assessment of the condition of the dwelling, although the condition of the dwelling does not directly measure interior quality. However, it does correlate well with the other measures (see Table 6).

Number of landlord-supplied appliances is the next attribute used to measure interior quality. That number replaces attributes identifying the type of appliance supplied because the number indicates well what is supplied (see Table 7). Nearly 85 percent of dwellings with two landlord-supplied appliances have a stove and a refrigerator. About 90 percent with three appliances have a stove, refrigerator, and dishwasher. The fourth appliance supplied by the landlord is nearly always an air conditioner.

The coefficient of reproducibility for Guttman scales measures how well the number of appliances predicts the type of appliances supplied. Mathematically, it equals one minus the number of errors (e.g., number

Table 5

DISTRIBUTIONS AND WEIGHTS FOR COMPONENTS OF INTERIOR QUALITY

Component	Distribution of Rating (%)				Weight
	Very Bad	Poor	Fair	Good	
Window rating	.9	6.3	27.8	66.0	.25
Wall and ceiling rating	1.0	5.4	27.4	66.2	.25
Floor and floor covering rating	1.2	6.6	33.2	59.0	.25
Building rating	1.0	6.2	30.6	62.2	.25

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

NOTE: All variables are derived from household survey responses.

Table 6

CORRELATION MATRIX FOR COMPONENTS OF INTERIOR QUALITY

Row	Component	Column			
		1	2	3	4
1	Window rating	1.00			
2	Wall and ceiling rating	.42	1.00		
3	Floor and floor covering rating	.42	.52	1.00	
4	Building rating	.50	.56	.51	1.00

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

NOTE: All variables are derived from household survey responses.

of dwellings having one appliance that is not a stove) divided by the total number of responses.* If that coefficient exceeds .90, then substituting the number of appliances for the type of appliances entails no loss of information. Here the coefficient equals .961.

*The total number of responses here equals the number of dwellings times the number of responses, or 1,736 × 5 = 8,680.

Table 7

CONDITIONAL DISTRIBUTION OF DWELLINGS WITH LANDLORD-SUPPLIED APPLIANCES

Number of Appliances Supplied by Landlord	Dwellings with Landlord-Supplied Appliances (%)				
	Stove	Refrigerator	Dishwasher	Air Conditioner	Disposal
1	75.2	5.4	16.1	3.3	0.0
2	98.1	85.4	13.9	1.9	0.7
3	99.5	97.0	91.9	10.6	1.0
4	100.0	100.0	99.6	97.3	3.3
5	100.0	100.0	100.0	100.0	100.0

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

NOTE: Number of landlord-supplied appliances is calculated from tenants' responses.

The price for the squared number of landlord-supplied appliances is $1.11 per month, so that a dwelling with three such appliances would rent for $9.99 more per month than an otherwise comparable dwelling with no landlord-supplied appliances. One way to assess the reasonableness of that estimated price is to compute the present discounted value of a stove and refrigerator supplied by the landlord. Supplying those appliances would increase rent by $4.44 per month. Assuming they have a useful life of 20 years and that the real discount rate* is 2 percent per year, the present value of those appliances is $879.14, which was enough to pay for those appliances in 1974.

The next four attributes denote the presence of storage space, central forced air or steam heat, a thermostat that controls the amount of heat, and the location of the dwelling on property where additional dwellings were obtained by subdividing existing dwellings. Tenants supplied the information used to construct the first three attributes; landlords furnished information for the last attribute. Presence of storage space actually denotes presence of such space in the dwelling,

*A real rate takes into account the effects of price inflation.

garage, or any other area outside the dwelling. Presence of central forced air or steam heat indicates that those are the primary sources of heat as opposed to floor furnaces, wall heaters, built-in electric heat, portable room heaters, fireplaces, stoves, or no heat. Combining central forced air and steam heat into one attribute entails no loss of information or precision; previous regressions consistently yielded statistically indistinct prices, about $13.50 per month, for the two types of heat.

Presence of subdivided residential space is based on the landlord's response to "Were any units on your property obtained by subdividing existing residential space?" Although that attribute could refer to other dwellings on the property, it usually does not. More than 90 percent of the units for which subdivided residential space is present are located on properties with 2-4 dwellings. Those properties average about 2.25 dwellings per property; so for most dwellings in the data base used here, presence of subdivided residential space on the property ought to indicate that the dwelling itself was affected by subdividing.

Since subdivided dwellings probably have smaller rooms and less convenient interior layouts than others, they should rent for less than otherwise comparable dwellings, which is what the estimated price (-$4.84 per month) indicates.

Exterior Quality

The composite rating of exterior quality combines ten variables that rate the quality of a building's exterior. The trained field-workers who surveyed residential buildings supplied the data for all but one of those variables--the building rating supplied by the landlords. Table 8 gives the distribution of responses for all ten variables and the weights used to combine them; Table 9 shows how those variables correlate. The distributions imply that Brown County's buildings are well-maintained and that their quality varies little, which corresponds to other assessments of the county's housing stock. The weights chosen average the first six variables, which rate specific aspects of the exterior. This average yields another rating of overall condition, which is then averaged with the last four

Table 8

DISTRIBUTIONS AND WEIGHTS FOR COMPONENTS OF EXTERIOR QUALITY

Component	Distribution of Rating (%)				Weight
	Poor	Fair	Good	Excellent	
Roof rating	9.4	3.3	55.7	31.6	.03
Wall rating	4.6	7.4	52.7	35.3	.03
Window rating	.4	1.9	60.7	37.0	.03
Storm window rating	.2	3.1	56.1	40.6	.03
Sidewalk and driveway rating	.8	8.1	74.5	16.6	.03
Exterior repair rating	.8	10.4	61.8	27.0	.03
Overall cleanliness rating	.8	2.2	37.5	59.5	.20
Overall condition rating	.3	12.3	62.8	24.6	.20
Construction quality rating	.2	7.3	79.2	13.4	.20
Building rating	.1	1.6	29.4	76.4	.20

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

NOTE: All variables except building ratings are derived from responses of trained fieldworkers who completed the residential building surveys. Building rating is derived from landlord responses.

variables.* Combining these ratings into a single rating is valid because the correlations between the ten ratings imply that each partly measures exterior quality.

The next attribute, the composite rating of comparative building quality, averages landlord's, tenant's, and trained fieldworker's appraisals of how their building's condition compares with others in the area. Table 10 gives the distribution and weights for those three appraisals; Table 11 shows how well they correlate. The distributions here again indicate that Brown County's buildings have relatively even quality.

*The weight assigned to each of the first six variables is (1/6) × (1/5) = .03.

Table 9

CORRELATION MATRIX FOR COMPONENTS OF EXTERIOR QUALITY

Row	Component	Column 1	2	3	4	5	6	7	8	9	10
1	Roof rating	1.00									
2	Wall rating	.47	1.00								
3	Window rating	.35	.45	1.00							
4	Storm window rating	.23	.37	.52	1.00						
5	Sidewalk and driveway rating	.22	.29	.26	.28	1.00					
6	Exterior repair rating	.61	.70	.53	.44	.32	1.00				
7	Overall cleanliness rating	.28	.35	.36	.42	.22	.38	1.00			
8	Overall condition rating	.57	.68	.52	.48	.32	.93	.51	1.00		
9	Construction quality rating	.08	.15	.14	.02	.09	.15	.08	.15	1.00	
10	Building rating	.18	.22	.24	.23	.17	.26	.22	.28	.06	1.00

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

NOTE: All variables except building rating are derived from responses of trained field-workers who completed the residential building surveys. Building rating is derived from landlord responses.

Table 10

DISTRIBUTIONS AND WEIGHTS FOR COMPONENTS OF COMPARATIVE BUILDING QUALITY

Component	Comparative Quality (%)			Weight
	Worse	Similar	Better	
Landlord's rating	6.9	62.7	25.4	.33
Tenant's rating	15.1	67.3	17.6	.33
Fieldworker's rating	3.3	92.8	3.9	.33

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

NOTE: Variables are derived from responses to landlord, tenant, or residential survey questions that ask for ratings of the quality of the building compared to that of others in the area.

Table 11

CORRELATION MATRIX FOR COMPONENTS OF COMPARATIVE BUILDING QUALITY

Row	Component	Column		
		1	2	3
1	Landlord's rating	1.00		
2	Tenant's rating	.31	1.00	
3	Fieldworker's rating	.22	.16	1.00

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

NOTE: Variables are derived from responses to landlord, household, or residential building survey questions that ask for ratings of the quality of the building compared to that of others in the area.

Lot size per dwelling measures the amount of outdoor space available to tenants. It is truncated at 10,890 square feet (one-quarter acre), since previous regressions showed that more space does not contribute to the quantity of housing service.* Note that the price of such space, $1.27 per 1,000 square feet, does not equal the price of land. The former is constant in the cross section, whereas the latter is not. Here, location attributes control for variations in land prices.

Buildings with wood or composition siding supply less housing service than those whose exterior is aluminum, brick, stone, or cinder block, as evidenced by the estimated price: -$6.08 per month. Presence of wood or composition siding forms a single attribute because previous regressions showed that either reduces rent by about $6 per month.

Presence of a garage or carport indicates only whether such structures are on the property, not whether a dwelling's occupants have access to an enclosed or covered parking place. That distinction probably explains why garages and carports contribute so little to gross rent--only $3.16--which seems too small an amount, given the severity of winters in Brown County.

The next four attributes distinguish the density and type of property on which the dwelling is located. The excluded type here is a dwelling on a property with 2-4 units, none of which are duplexes. These attributes are included in the index to measure the effects of unobserved attributes such as style or attractiveness. The estimated prices indicate significant differences among dwelling types. Single-family homes rent for no more than the excluded class, whereas tenants on properties with 5-9 dwellings pay about $5.00 more per month. Tenants on properties with 10+ dwellings appear to pay more than tenants on properties with 5-9 units, but the difference is statistically insignificant. Only occupants of duplexes pay a large premium of $31 per

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*A linear function for lot size was fit, whose slope changed at one-quarter acre. Up to that point, the price of outdoor space was 75¢ per 1,000 square feet with a standard error of about 33¢. After that point, the price was zero. Such linear functions and their uses are discussed by Dale J. Poirier, *The Econometrics of Structural Change*, North-Holland Publishing Co., Amsterdam, 1976.

month.* Whether that premium is mostly due to higher hedonic prices or greater quantity is not clear. However, resolving that question is not critical because duplexes make up only 5 percent of the rental market. Moreover, the index adequately measures differences among duplexes regardless of which factor accounts for the size of the premium.

Location Attributes

The regression equation includes location attributes to avoid estimating biased prices for housing attributes and to break down gross rent into location and housing service. Here the effects of location on gross rent are measured by access to employment and neighborhood and by blockface attributes. These three groups of attributes correspond to increasingly narrower definitions of location. Generalized access uses data for all of Brown County. Neighborhood quality attributes use data that describe only the neighborhood in which the dwelling is located, whereas blockface quality attributes use data that describe only the specific blockface of the dwelling.

The attributes that make up those three groups account for the bulk of the variation in gross rents caused by locational differences, which, as we saw earlier, is small. Previous regressions included dummy variables that identified clusters of neighborhoods to test whether the regression should include other location attributes. Those variables were consistently insignificant.

Generalized Access to Employment

Generalized access to employment measures the closeness of dwellings to employment in Brown County. It is defined at the neighborhood level:

$$A_i = \hat{A}_i - \min_i \{\hat{A}_i\}$$

$$\hat{A}_i = \ln \left(E_i + \sum_{\substack{j=1 \\ j \neq i}}^{108} E_j / d_{ij}\right); \qquad i = 1, \ldots, 108, \tag{4}$$

*Unlike other properties with two dwellings, duplexes share a common wall.

where A_i = generalized access to employment for neighborhood i,
$\tilde{A}_i$ = a temporary variable,
ln = the natural logarithm,
$E_{i,j}$ = employment* in neighborhood i or j,
d_{ij} = the airline distance in miles between the centroids of neighborhoods i and j,
i = index of the 108 neighborhoods in Brown County.

For each neighborhood the sum in parentheses weights employment in other neighborhoods by its airline distance from the neighborhood and adds the resulting values to the neighborhood's employment. The neighborhood's residents thus have access to employment that varies directly with the number of jobs and inversely with how far away they are. Logarithmically transforming that sum makes successive increments to employment have declining effects on access. Finally, subtracting access's minimum value arbitrarily rescales access, so that its minimum value is zero.**

As predicted by the economic theory that describes housing prices in a spatial setting, access to employment has a positive price. Access has value because increasing it reduces the cost of commuting to and from work and because there is a fixed supply of land. Here, a dwelling with average access rents for about $15 more per month than a dwelling with minimum access.

Neighborhood Quality

The composite rating of neighborhood quality as well as the fraction of the neighborhood that is open space measure neighborhood quality. Both attributes are defined at the neighborhood level, so all dwellings in a neighborhood have the same values. The composite ratings average

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*Estimated from responses supplied by households.

**Access to employment is not the only attribute with an arbitrary zero point. Other attributes, especially those that rate quality, also have arbitrary zero points. The effects of that arbitrariness are discussed later.

trained fieldworkers' ratings of each blockface's buildings, yards, and cleanliness.* Table 12 distributes those ratings among four categories and gives the weights used to combine the ratings, which indicates that a simple average was used. The ratings are highly correlated (see Table 13), implying that the ratings correspond to a single attribute.

The positive price for neighborhood quality demonstrates that the market values that externality. Tenants pay about $9 per month for each one-unit increase in neighborhood quality.

The fraction of the neighborhood that is open space** measures residents' access to that space. Its positive price shows that most people value such access. Open space can add as much as $8.53 per month to gross rent or about 6 percent of average monthly gross rent.***

Blockface Attributes

The presence of consumer shops, institutions such as schools, and above average landscaping are attributes that measure blockface quality.† The estimated price of each attribute is about $5 per month absolute value, and the signs are reasonable. Dwellings on blockfaces with consumer shops or institutions command smaller gross rents, probably because the presence of such establishments leads to congestion, noise, and possibly vandalism. On the other hand, dwellings on blockfaces with above average landscaping rent for more than otherwise comparable dwellings, suggesting that this externality also has value in the marketplace.

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*Brown County is composed of about 8,300 such blockfaces, each of which was rated by trained fieldworkers. For a general assessment of the data they gathered and specific assessment of the ratings used here, see C. Lance Barnett, *Audit of the Baseline Neighborhood Survey in Site I*, The Rand Corporation, WN-9732-HUD, April 1977 (forthcoming as N-1115-HUD).

**Open space is the portion of each neighborhood's total acreage devoted to public parks, golf courses, woodland, and agriculture. It is derived from land use data collected by the Brown County Planning Commission.

***The maximum value for the fraction is .86 and the price per month is $9.92, so (.86)($9.92) = $8.53.

†All three attributes are based on observations by trained fieldworkers who completed the survey of residential buildings.

Table 12

DISTRIBUTIONS AND WEIGHTS FOR COMPONENTS OF NEIGHBORHOOD QUALITY

Component	Distribution of Rating (%)				Weight
	Poor	Fair	Good	Excellent	
Building rating	15.8	42.9	22.6	18.7	.33
Yard rating	15.3	48.9	29.2	6.6	.33
Cleanliness rating	24.8	55.3	19.5	.4	.33

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

NOTE: Variables are derived from trained fieldworkers' ratings of individual blockfaces.

Table 13

CORRELATION MATRIX FOR COMPONENTS OF NEIGHBORHOOD QUALITY

Row	Component	Column		
		1	2	3
1	Building rating	1.00		
2	Yard rating	.88	1.00	
3	Cleanliness rating	.87	.82	1.00

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

NOTE: Variables are derived from trained fieldworkers' ratings of individual blockfaces.

Price Adjustments

Although the theory presented above states that the market clearing price of housing and location services is a constant, the prices actually paid can vary. Most of that variation is essentially random, but some can be explained by the nature of relationships between tenants and landlords. The regression fit here includes variables that

characterize those relationships. The effect of those variables is to adjust the prices actually paid so that they are closer to the market clearing prices.

Length of Stay

Most hedonic indexes fit for rental housing find that the longer tenants stay in a dwelling, the more their rent drops relative to what new tenants would pay.* Exactly why tenants who stay receive discounts is unclear. One explanation is that those tenants may reduce maintenance costs for landlords who then return that saving as discounts. Another explanation is that landlords may value the steady income provided by long-staying tenants and may buy that stability with discounts.

Here the effect of tenants' length of stay on gross rent is modeled with a spline function that bends at 3.5 years. Each year of residence before 3.5 years reduces rent by about $4.50 per month. After 3.5 years, rents stop declining.** The maximum discount at 3.5 years equals about $16.00 per month or about 11 percent of average monthly gross rent.

Tenants' Satisfaction with Dwelling

Tenants' satisfaction with their housing was included in the index to measure the effects of attributes that were hard to quantify (e.g., style or superior interior layouts). If satisfaction measured such effects, it should have had a positive price. However, the coefficient for tenants' satisfaction is significantly negative, suggesting that it actually measures whether tenants have a "good deal." Assuming that housing and location attributes accurately measure quantities, tenants' satisfaction would rise as the price of housing or location services fell relative to the market clearing prices. For that reason, tenants' satisfaction belongs with other variables that adjust for price differences.

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*See, for example, Merrill, *Draft Report on Hedonic Indices.*

**Spline functions are piecewise linear. Along the jth piece the slope equals the sum of the slopes for the previous $j - 1$ pieces plus the slope for the jth piece. For lengths of stay exceeding 3.5 years, the slope is $-4.45 + 3.86 = -.59$, which is indistinguishable from zero.

Presence of a Resident Landlord

Landlords living on their property may choose tenants more carefully than other landlords, primarily because their tenants are also their neighbors. They might also retain desirable tenants by offering rent discounts. The estimated coefficient is consistent with such behavior. However, its value is small (-$2.12 per month) and is not significantly different from zero.

The Constant Term

The constant term should equal zero, so that setting all attributes equal to zero implies a monthly gross rent that equals zero; that is, dwellings that supply nothing command no rent. The constant term, however, is significantly negative, -$35.58 per month. The regression fits a negative constant term because the zero points chosen for the attributes, especially the composite ratings, are on average less than their true zero points.* The following equations justify that explanation. Consider the bivariate regression

$$R = -a + b(X + c), \qquad (5)$$

where R = monthly gross rent,

$-a$ = the negative constant term,

b = the estimated (positive) price of attribute X,

X = an attribute,

c = the difference between the chosen and true zero point for X.

Setting R and X equal to zero and rearranging terms yields

$$c = a/b,$$

*Excluding important attributes from the regression could also produce a similar result; however, as shown below, that is not the issue here. Also, our work on the hedonic index for St. Joseph County supports the explanation advanced here. That index has only two composite ratings, and the constant there is statistically indistinguishable from zero. See Charles W. Noland, *Hedonic Indexes for St. Joseph County, Indiana*, The Rand Corporation, N-1305-HUD, forthcoming.

so that c is greater than zero, which implies that the true zero exceeds the chosen zero.*

The differences between true and actual zero points do not impair the index's ability to measure differences in the services provided, since such measurement depends only on differences in the attributes' values, in which case the true zero points net out. The index can thus be used to estimate marginal propensities to consume individual attributes such as rooms and summary attributes such as space. Those differences, however, do mean that measurements on the attributes cannot be converted into percentages, since those differences imply that attributes are not measured on a ratio scale. In particular, expenditures on attributes cannot be used to estimate such elasticities as the income elasticity of the demand for space.

APPRAISING THE INDEX

The preceding portion of this section presented the index, documented the attributes measuring housing and location service, and when possible, assessed the signs and sizes of the estimated prices. In general, it found nothing amiss. The remainder of this section appraises the index's ability to accurately measure differences in the quantity of housing or location services supplied or consumed.

The standard error of the estimate measures how closely the regression equation fits the data and indicates the degree of confidence with which the regression can estimate rent or measure differences in the amount of services supplied or consumed. As shown in Table 14, the standard error here is smaller than those of other hedonic indexes.** The standard errors presented in that table have about the same or

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*It is possible to compute zero points for the attributes that yield zero for the constant term. However, the new zero points would not necessarily equal the true points.

**Unlike R^2s, which equal the fraction of the dependent variable's variation explained by the regression equation, standard errors can be meaningfully compared across data bases and in some instances across specifications.

Table 14

STANDARD ERRORS FOR HEDONIC INDEXES FIT TO EXPERIMENTAL HOUSING ALLOWANCE PROGRAM: DATA FOR RENTAL HOUSING

Institution and Housing Market	Standard Errors of the Estimate	
	$/Month	As Percent of Average Rent
Rand		
Brown County WI	20.00	15.3
Abt Associates		
Pittsburgh PA	19.99	18.8
Phoenix AZ	22.33	18.0
Urban Institute		
Pittsburgh PA	23.98	28.9
Phoenix AZ	29.90	29.5

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County; and from data in Sally Merrill's *Draft Report on Hedonic Indices as a Measure of Housing Quality*, Abt Associates, Cambridge, Mass., Report 76-9612, 23 December 1977, and from Jeanne E. Goedert, Larry J. Ozanne, Robert W. Tinney, and Joseph J. Valenza, *The Integrated Analysis of Housing Quality Improvements: Two Initial Approaches*, The Urban Institute, Washington, D.C., WP 216-15, 17 June 1975.

larger absolute values, but when expressed as a percentage of average rent, the error is noticeably smaller. Thus, the index fit here should be at least as accurate as those fit by others.

Having a nontrivial standard error for the regression equation raises the question: Are the errors systematic or random? Either incorrectly specifying attributes' functional forms or excluding important attributes from the regression would generate systematic errors. If such systematic errors occurred, the index would be biased. On the other hand, if the errors are random, the index ought to be unbiased. Determining which type of error prevails is most easily done by plotting

residuals against predicted values of the dependent variable and against independent variables. Because the logarithm of rooms is the index's most significant variable, a residual plot for that variable is reproduced here.

The figure plots average residuals of gross rent for each size of dwelling against the regression estimate, the latter displayed as a solid line. The distribution of residuals indicates that the room variable is correctly specified by the natural log form and that no important attributes correlated with rooms were excluded from the index.

Another test for the presence of specification error is to regress on the index's residual total household income, which would contain any excluded attributes. They should be normal goods, so their consumption should vary directly with income. A significant coefficient for income would then indicate that some important attributes had been excluded from the index, raising the possibility that the estimated prices are biased.*

Although income's coefficient differs significantly from zero (it is positive), what was excluded did not bias the estimated attribute prices. Income explains very little of the variation in the index's residual: The standard error of the estimate for this ancillary regression is $19.77 per month versus $20.00 per month variation for the index's residual, and its R^2 is less than .01. Moreover, when income is included in the hedonic index, none of the estimated attribute prices change very much.** In fact, none changed by more than one standard deviation.

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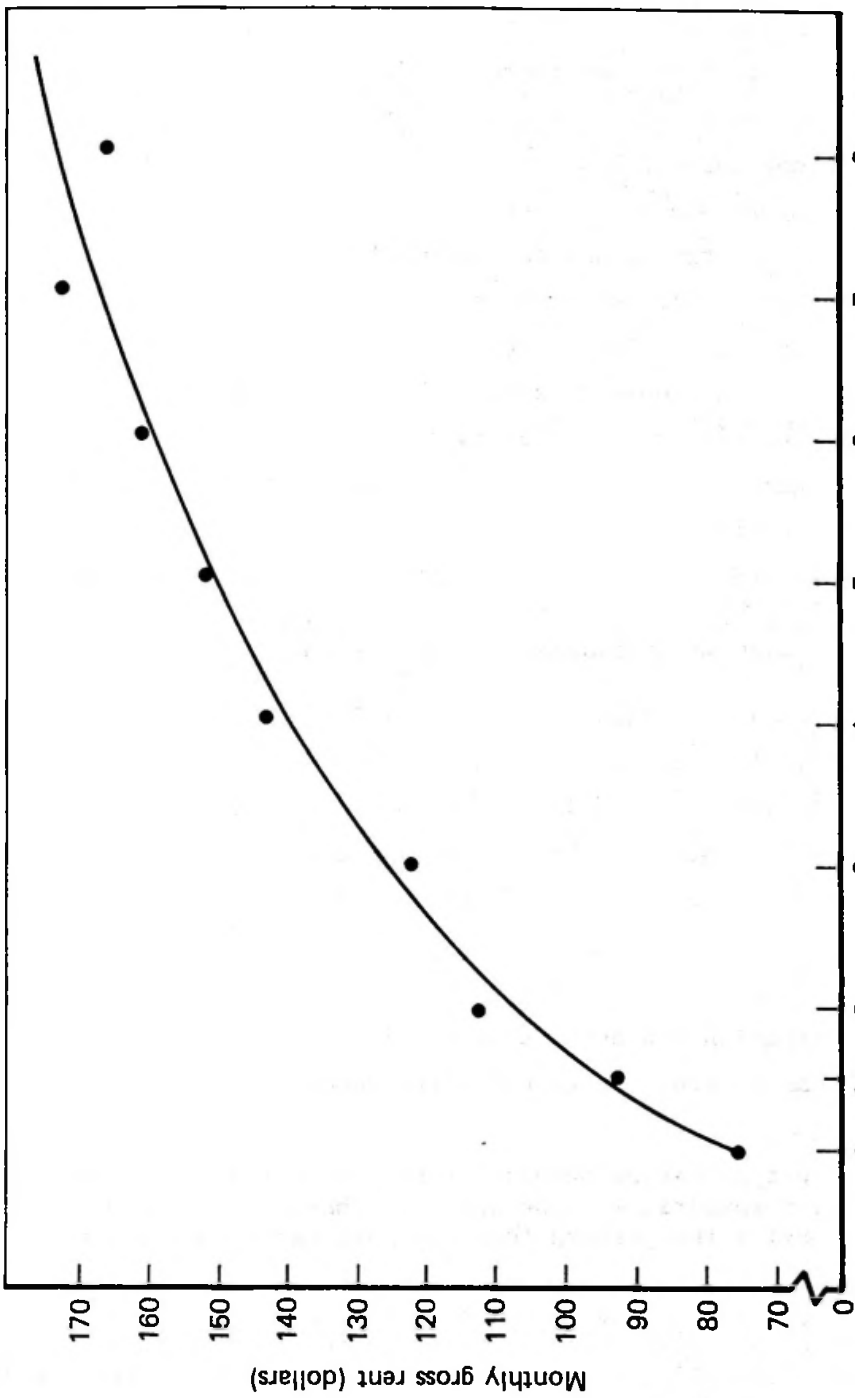
*The degree of bias depends directly on the correlations between included and excluded attributes as well as on the prices for the excluded attributes.

**Variation in the residuals, although not caused by a major misspecification, may be price variation occurring because individuals' knowledge of the housing market is imperfect and acquiring information is costly. Thus, specific transactions between a household and a landlord may take place at prices higher or lower than the expected market clearing prices. If the expected prices do not systematically vary within the market, then variation in the transaction prices does not adversely affect the index. It induces no bias, but does reduce the index's accuracy.



Effect of number of rooms on gross rent

The presence of significant dwelling-type premiums in the marketwide index could be brought about in part by specification errors--either misspecification of included attributes or by excluded attributes.* If those errors affect only a few attributes, their effect could be compensated for by transforming those attributes.** Here, however, the errors affected more than just a few attributes. Fitting five separate regressions, each of which includes all interactions between the variables that compose one summary attribute (i.e., space, interior quality, etc.) and dwelling types, and testing whether the interaction terms have nonzero coefficients indicates that the errors affect all attributes except those of residential space (see Table 15). Since space is one of the most important determinants of rent, finding that it is again unaffected by specification error is reassuring.

Introducing the interaction terms (overall more than 90 were used) only slightly affects the regression's predictive power. The highest R^2 obtained exceeds that for the marketwide regression by less than 1.5 percentage points; the smallest standard error is only $.27 less per month than that for the marketwide regression, which was obtained when the interactions between dwelling type and interior quality were included. That outcome is understandable. The attributes that the marketwide index excludes are probably the most subtle measures of quality, ones that ought to be most highly correlated with dwelling type and the included measures of interior quality.

CONCLUSIONS

The information presented thus far indicates that the index should accurately measure cross-sectional differences between dwellings. No

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*Dwelling type per se should not be considered an attribute, because it simply summarizes those features that cause some dwellings to yield more service than others (e.g., single-family homes and privacy).

**Included attributes can be transformed to account for excluded attributes. Consider rooms and average room size in square feet: If average room size varies across dwellings, then an interaction term between type of dwelling and average room size could be included to account for such variation.

Table 15

TESTS FOR PRICE DIFFERENCES BY ATTRIBUTE GROUP

Interaction Terms Tested	Number of Terms	*F*-value
Space attributes with dwelling-type indicators	8	1.16
Interior quality attributes with dwelling-type indicators	24	2.94[a]
Exterior quality attributes with dwelling-type indicators	20	3.16[a]
Location attributes with dwelling-type indicators	24	2.10[a]
Price adjustments with dwelling-type indicators	15	2.24[a]

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

NOTE: Attributes that compose each attribute group described above are defined in Table 1.

[a]Significant at 95 percent confidence level.

estimated coefficients have signs that cannot be reasonably explained. With only one exception those signs agree with what a priori reasoning would imply they should be. The prices also appear to have reasonable magnitudes. The index's standard error is no larger than that of other studies, and when expressed as a percentage of average rent, it is smaller. Tests for specification errors found no evidence for the presence of significant error, which suggests that the index is unbiased.

III. USING THE INDEX

A hedonic index for housing service can be used to transform measurements on attributes into measures of service that are comparable, only if the attribute prices do not differ between dwellings. That invariance is what allows attributes of dwellings and their locations to be treated as if they were a single good, that is, a composite commodity. This section first verifies that attribute prices are sufficiently constant across dwellings to treat housing as a composite commodity. Having established that, this section then uses the index to examine two aspects of consumer behavior: the relative effectiveness of alternative ways that renters search for dwellings, and the effect of income on renters' consumption of the attributes of dwellings.

HOUSING AS A COMPOSITE COMMODITY

Goods, such as the attributes of dwellings and their locations, can be treated as if they were a single commodity so long as their relative prices do not vary in the situation being studied.* One advantage of having goods thus related is that consumer behavior with respect to them can be more easily analyzed. This is so because the prices of those goods can be used to coalesce measurements on them into a scalar measure of the quantity of services supplied.

Here I will test whether the attribute prices vary between dwellings. Two factors could cause such variation. One is the existence of demand-based submarkets, which could support distinct vectors of attribute prices. The other is differences in the supply function of dwellings which, even in the longrun, could induce distinct vectors of attribute prices.

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*For the formal theory supporting that assertion, see J. R. Hicks, *Value and Capital*, Oxford Press, Oxford, England, 1939, pp. 33-34, 312-313. For a more general composite commodity theorem, see Nissan Liviatan, "A Generalization of the Composite-Good Theorem for Imperfect Markets," *Review of Economic Studies*, Vol. 33, 1966, pp. 45-56.

For any housing market to divide into submarkets supporting different attribute prices, several conditions must hold. First, the market must contain groups of consumers who prefer one type of dwelling (however defined) to another. Second, their demands (relative to supply) must differ across dwelling types. Third, the cross-elasticities of demand between dwelling types must be near zero. The first two conditions allow demand to concentrate in potential submarkets; the last condition keeps demand differences focused in those submarkets, so that different attribute prices can emerge.

The third condition, fundamental to the existence of submarkets supporting distinct attribute prices, was unlikely to have prevailed in Brown County in 1974. The only plausible circumstances that could bring about near zero cross-elasticities are extensive market segregation or, in the shortrun, a sudden demand surge. Brown County is characterized by an unusually homogeneous population: Ethnic identification is low, and less than 2 percent of its households are headed by a minority.* Thus, the usual bases for market segregation are absent. As for a sudden demand surge, the available evidence argues against it. Our studies of property values indicate that prior to 1974 they were rising at the same rate as consumer prices in general.** Our study of rent inflation after 1974 indicates that Brown County's rents rose at rates comparable to those of other cities in the North Central region and the nation during the three years after 1974.***

Even though attribute prices were not likely to have differed because of demand factors, supply functions may vary because of differing production technologies. The dimension along which they would most likely differ is dwelling type;† it is reasonable to suppose that

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*Kevin F. McCarthy, *Housing Choices and Residential Mobility in Site I at Baseline*, The Rand Corporation, WN-9029-HUD, August 1976 (forthcoming as N-1091-HUD).

**See the *Third Annual Report of the Housing Allowance Supply Experiment*, The Rand Corporation, R-2151-HUD, February 1977, pp. 68-70.

***See Stucker, *Rent Inflation in Brown County, Wisconsin: 1973-78*.

†Five dwelling types are distinguished here, four of which are included in the marketwide index: single-family homes, duplexes, dwellings on 5-9 dwelling properties, and dwellings on 10 or more dwelling properties. The excluded category is composed of dwellings on 2-4

single-family homes use a different technology than apartments in large structures. To test for differences in attribute prices, four regressions were fit, each of which included all interaction terms between one of the dwelling types identified in the marketwide regression and all other attributes (including price adjustments) in the regression. Table 16 presents *F*-values to test the null hypothesis that those interaction terms have coefficients that equal zero.* Only for single-family homes can the null hypothesis be accepted. For the other three dwelling types, there are significant price differences.

Those price differences, however, are not operationally important. Table 17 summarizes the differences between using the marketwide index and subindexes that incorporate price variations by dwelling type to measure changes in the quantity of services as attributes vary.** None of the differences is statistically distinct. The largest absolute difference is less than the marketwide index's standard error. The average absolute differences are small; for duplexes that difference is less than 8 percent of their average monthly gross rent of $179.

EFFECTS OF SEARCH STRATEGIES

McCarthy has used the index's residual to measure the effectiveness of various search strategies renters use to find homes that are bargains*** (i.e., dwellings renting at a discount). Such use of the residual is valid because the index used here sufficiently controls for quantity (leaving only price variation in the residual). Price

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dwelling properties that are not duplexes. For ease of explanation, the last three types will be referred to as 5-9, 10+, and 2-4, respectively.

*These tests are functionally equivalent to tests of whether the vector of coefficients for a given dwelling type differs from a single vector for the remaining types.

**The differences were obtained by using the marketwide index and an index fit to data for the indicated dwelling type to predict monthly gross rent for five vectors of independent variables: (a) the submarket's means less two standard deviations, (b) less one standard deviation, (c) untransformed, (d) plus one, and (e) plus two standard deviations.

***Kevin F. McCarthy, *Housing Search and Residential Mobility*, The Rand Corporation, R-2451-HUD, September 1979.

Table 16

TESTS FOR PRICE DIFFERENCES
BY DWELLING TYPE

Interaction Terms Tested	Number of Terms	*F*-value
Single-family homes with all other attributes[a]	22	1.28
Duplexes with all other attributes[a]	23	2.36[b]
5-9 dwellings on property with all other attributes[a]	23	2.73[b]
10+ dwellings on property with all other attributes[a]	23	2.12[b]

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

[a]Excludes indicator variables for the other dwelling types.

[b]Significant at 95 percent confidence level.

Table 17

DIFFERENCES BETWEEN MONTHLY GROSS RENTS PREDICTED
USING MARKETWIDE INDEX AND SUBINDEXES

Dwelling Type	Differences Between Predictions	
	Average of Absolutes	Maximum
Duplexes	13.08	21.80
5-9 dwellings on property	2.88	4.80
10+ dwellings on property	3.45	6.01

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys for Brown County.

discounts and premiums are measured by

$$P' = \frac{R - \hat{R}}{\hat{R}} = \frac{PQ - \overline{P}Q}{\overline{P}Q} = \frac{P - \overline{P}}{\overline{P}}, \qquad (6)$$

where P' = the relative price of a dwelling,

R = gross rent,

$\hat{R}$ = predicted gross rent,

P = price paid in a dwelling,

Q = quantity of services supplied,

$\overline{P}$ = hedonic price for residential services.

The substitution of $\overline{P}Q$ for $\hat{R}$ is justified because dwellings can be treated as a composite commodity.

When P' is regressed on variables indicating how households searched for their dwellings as well as on the characteristics of those households, the only strategy found that consistently ferrets out bargains is finding the dwelling through tips from friends. That same regression also shows that households eligible for the housing allowance program occupy bargain dwellings, presumably because they face competing demands for their meager budgets and so emphasize price in their housing choices.

MARGINAL EXPENDITURES FOR SUMMARY ATTRIBUTES

Table 18 shows marginal expenditures on four summary attributes (space, interior quality, exterior quality, and location) and total residential services as a function of income.* Marginal rather than absolute expenditures are used because the index is capable only of measuring differences. The marginal expenditures equal the difference between the expenditures of low-income households (i.e., those whose annual income is less than $5,000) and what households in each income bracket actually

*Tables 18 and 19 cannot predict the effects of increasing renters' income, because as income rises, some renters would choose to become owners (whose consumption patterns are known to differ from those of renters, even controlling for income).

Table 18

MARGINAL EXPENDITURES ON SUMMARY ATTRIBUTES AS INCOME INCREASES: HOUSEHOLDS WITH INCOMES OVER $5,000

Income Category	Marginal Expenditure ($/mo.) Relative to Low-Income Families[a]				
	Space[b]	Interior Quality[b]	Exterior Quality[b]	Location[b]	Residential Services[c]
$5,001-7,500	-.81	3.44	2.71	.45	5.79
$7,501-10,000	2.24	3.24	3.86	.29	9.33
$10,001-12,500	4.65	4.19	6.18	1.31	16.33
$12,501-15,000	4.28	7.43	10.88	1.93	24.52
$15,001-17,500	4.21	7.55	8.77	.29	20.82
$17,501-20,000	9.84	8.08	15.40	1.97	35.29
$20,001+	7.01	9.45	17.71	2.34	36.51

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys in Brown County.

NOTE: Table entries are computed by subtracting average predicted expenditure for families whose annual income is less than $5,000 from remaining average predicted expenditure.

[a] Families whose annual income is less than $5,000.

[b] See Table 1 for attributes in each hedonic good.

[c] Predicted gross rent plus price adjustments.

spend. The highest income renters, for example, spend $7.01 more per month for space than the lowest income households.

Expenditures on summary attributes were computed by multiplying the value of each component by its price and summing the products.* Expenditures on space, for example, equal $46.70 times the natural logarithm of the number of rooms, plus $18.86 times the number of bathrooms.

Several conclusions can be drawn from the patterns in Table 18. First, renters' marginal propensity to consume residential service** is

*Table 4 gives the estimated prices for the individual attributes and identifies the attributes that compose each summary attribute. Since prices are constant, marginal expenditures equal marginal consumption.

**Residential service equals monthly gross rent plus the price discounts that accrue with length of stay and those due to tenants' satisfaction and presence of a resident landlord.

very small. Families whose annual income falls between $17,501 and $20,000 spend only $29.50 more per month than families whose annual income falls between $5,001 and $7,500. Differencing the midpoints of those intervals and dividing by 12 to obtain monthly income yields a marginal propensity to consume residential services of $.03 per month; this means that an extra dollar of monthly income causes housing consumption to increase by $.03. That number is consistent with current income elasticities we estimate using data for Brown County.*

Second, most increased consumption is brought about by better exterior and interior quality, a fact consistent with the finding on the relative importance of the attributes. The highest income households spend $36.51 more per month than the lowest income households. Nearly 75 percent of that difference ($27.16 out of $36.51) is accounted for by increased expenditures on the quality attributes; almost 50 percent is due to increased expenditures for exterior quality alone. Thus, higher income households appear to prefer "better" housing to "more" housing.

Finally, expenditures for location have a very irregular relationship to income. Table 19, whose format and entries were obtained in the same manner as Table 18, shows that the irregularity is caused by shifting composition in the location attributes. As income rises, renters purchase less access to employment. On the other hand, they buy better neighborhoods. In Brown County, those expenditure changes tend to offset one another, yielding the irregular pattern observed in Table 18.

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*See John E. Mulford, *The Income Elasticity of Housing Demand*, The Rand Corporation, R-2449-HUD, July 1979. He estimates that renter's current income elasticity of expenditures is about .15. Assuming an average expenditure share of .25, the implied marginal propensity to consume is .0375.

Table 19

MARGINAL EXPENDITURES ON LOCATION ATTRIBUTES AS INCOME INCREASES RELATIVE TO LOW-INCOME FAMILIES

Income Category ($/yr)	Marginal Expenditures Relative to Low-Income Families[a] ($/mo.)			
	Access to Employment	Neighborhood[b] Quality	Blockface[b] Quality	Location[c]
$5,000-7,500	-.83	1.33	-.05	.45
$7,501-10,000	-1.66	1.95	0.00	.29
$10,001-12,500	-1.37	2.18	.50	1.31
$12,501-15,000	-1.81	3.69	.05	1.93
$15,001-17,500	-3.53	3.75	.07	.29
$17,501-20,000	-3.00	4.32	.65	1.97
$20,001+	-2.20	4.04	.50	2.34

SOURCE: Tabulated by author from 1,736 records of baseline household, residential building, neighborhood, and landlord surveys in Brown County.

NOTE: Table entries are computed by subtracting average predicted expenditure for families whose annual income is less than $5,000 from remaining average predicted expenditures.

[a] Families whose annual income is less than $5,000.

[b] See Table 1 for attributes in each hedonic good.

[c] Expenditure on location equals the sum of expenditures on access to employment, neighborhood quality, and blockface quality.

IV. CONCLUSIONS

The purpose of this report has been to present and appraise the usefulness of a hedonic index fit to marketwide data describing Brown County's rental housing stock in 1974. All evidence for that appraisal is now available. Section II showed the relative importance of the five groups of variables that compose the regression with which the index was fit: Location attributes are unimportant, as are price adjustments; attributes of dwellings are the most important. Section II also discussed the 27 attributes and price adjustments used to fit the index. With one exception (tenants' satisfaction with their dwellings) their signs and magnitudes were generally reasonable. When external evidence was available, it confirmed that the magnitudes of the coefficients were roughly correct. Tests for specification error showed that although the index does exclude some attributes valued by the market, their exclusion does not adversely affect the accuracy with which the index can measure contemporaneous differences among dwellings.

After verifying that dwellings can be treated as a composite good, Sec. III showed two ways the index can be used to analyze household behavior. It first showed how the index was used to determine whether search strategies adopted by renters significantly affected the price they paid. The main finding there was surprising but plausible: The best way to find housing bargains is through tips from friends. The index was also used to study how renters change their expenditures on four summary attributes as their income rises. Consumption of space varies much less with income than does consumption of interior and exterior quality; so higher income renters buy "better" rather than "more" housing. Changes in the last two summary attributes account for about 75 percent of the increased consumption of residential services (housing plus location services). Although the amount renters spend on location does not vary with income, what they buy does. Higher income renters live farther from the center of town, giving up access in order to occupy better neighborhoods.

The index might also be used to measure changes in housing services brought about by the housing allowance program. It is unlikely, however, that the program will affect many of the attributes that compose the index. All but three dwelling attributes (the composite ratings) refer to structural characteristics of the dwelling that would change only by substantial rehabilitation or remodeling. The allowance program rarely induces such remodeling.* Certainly it is improbable that the allowance program will affect the location attributes of dwellings. Therefore I predict that the index will not distinguish allowance-induced changes from zero. Nonetheless, the index is a valuable tool for analyzing the characteristics of Brown County's rental housing market and the behavior of its participants.

One obvious use of the index would be to estimate expenditure functions for the summary attributes. Such functions would incorporate the effects of differences in household size, life-cycle stage, assets, and household income. Once such functions were fit, they could be used with data on allowance recipients to determine how receiving allowance income affected recipients' choice of summary attributes. Another use of the index would be to compute differences in the prices of neighborhoods (i.e., how much more it costs to live in neighborhood A compared with neighborhood B). If those differences were substantial, they would provide an explanation for the program's lack of interneighborhood mobility.**

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*See James L. McDowell, *Housing Allowances and Housing Improvement*, The Rand Corporation, N-1198-HUD, September 1979.

**The *Fourth Annual Report of the Housing Assistance Supply Experiment*, The Rand Corporation, R-2302-HUD, May 1978, presents early findings on the program's effects on recipients' mobility.

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